OPERATING CHARACTERISTICS OF A SEALED-PROTOTYPE Cs-Ba TACITRON

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Abstract

Tacitrons[1,2] are triode gas-discharge tubes, similar in construction to thyratrons. The primary functional difference between a tacitron and a thyratron is that the tacitron is designed to be completely grid-controlled, whereas a thyratron has grid control only over ignition. Demountable cesium-barium (Cs-Ba) tacitrons have exhibited very low forward voltage drops in the range of a few volts, hold-off voltages greater than 200 V, and average conduction current densities greater than 10 A/cm^2. These characteristics yield an average power switching density on the order of 10^3 W/cm^2 approaching 95% peak switching efficiency[3]. This parameter regime places the Cs-Ba tacitron in the range of conventional solid-state devices, with the advantage that the tacitron should reliably operate in extremes of temperature and radiation. The sealed prototype Cs-Ba tacitron discussed herein is intended to demonstrate "off-the-shelf" operation, taking the first step in moving the tacitron from a laboratory device to the performance level of a commercial product.

Introduction

A prototype sealed-volume Cs-Ba tacitron (SP1) has recently been designed and fabricated at the Russian Scientific Center, Kurchatov Institute, and tested by the University of New Mexico's Pulsed Power and Plasma Sciences Laboratory. Test results will be used to recommend design modifications for future sealed tacitrons. This paper makes a brief comparison between the basic operating characteristics of the sealed prototype to the characteristics of demountable Cs-Ba tacitrons previously studied at the University of New Mexico's Institute for Space Nuclear Power Studies[3-11]. Nominal electrode surface areas are 2 cm^2 in common with previously tested demountable devices, but the sealed prototype has internal cesium and barium reservoirs whose temperature (i.e., vapor pressure) is determined by location within the device, unlike the demountable devices which require separate heaters for externally provided Cs and Ba reservoirs. The present sealed prototype is designed to operate in a vacuum, with a maximum envelope temperature of 500° C at a nominal cathode temperature of 1150° C. Gas management includes the use of an inner "sealed" volume that encompasses the anode, grid, cathode, and electrode insulators. The Ba reservoir is located within the inner volume in an annular space adjacent to the emitter heater tube. This location provides good temperature control for the Ba reservoir and reduces barium condensation on the cooler surfaces in the outer volume. The Cs reservoir is easily accessible for thermal control, and is presently fitted with radiator fins to control reservoir temperature. It is anticipated that the design modifications required to reduce the envelope temperature for use in atmosphere or oil would be straightforward.

Description of Sealed Cs-Ba Tacitron Prototype

Fig. 1 shows a schematic diagram of the sealed prototype. The sealed prototype has a metallic outer envelope composed primarily of stainless steel, rather than an insulating envelope such as alumina. This design choice circumvents the problems inherent in using a metal-to-ceramic braze in the presence of reactive metal vapors. The

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14. ABSTRACT
Tacitrons[l,2J are triode gas-discharge tubes, similar in construction to thyratrons. The primary functional difference between a tacitron and a thyratron is that the tacitron is designed to be completely grid-controlled, whereas a thyratron has grid control only over ignition. Demountable cesium-barium (Cs-Ba) tacitrons have exhibited very low forward voltage drops in the range of a few volts, hold-off voltages greater than 200 V, and average conduction current densities greater than 10 Ncm2. These characteristics yield an average power switching density on the order of 103 W/cm2 approaching 95% peak switching efficiency[3l. This parameter regime places the Cs-Ba tacitron in the range of conventional solid-state devices, with the advantage that the tacitron should reliably operate in extremes of temperature and radiation. The sealed prototype Cs-Ba tacitron discussed herein is intended to demonstrate "off-the-shelf'' operation, taking the first step in moving the tacitron from a laboratory device to the performance level of a commercial product.

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outer envelope contains two sapphire insulators brazed to refractory metal shells -- one each in the upper and the lower regions of the prototype. These sapphire insulators are located in relatively low temperature regions and are necessary in order to electrically isolate the collector, grid, and emitter structures within the device. Sheet metal arc shields are provided internally to shield the sapphire insulators from the Cs plasma during conduction and thereby prevent surface flashover across the insulator.

The base of the prototype is electrically connected to the emitter while the upper portion of the prototype is electrically connected to the collector. Both the emitter and collector electrodes are machined from molybdenum. The grid electrode feedthrough is located near the switching region. The Cs reservoir, fitted with radiator fins and located at the top of the device, is cylindrical in geometry. A hollow tube rising through the base of the cylinder permits Cs vapor to pass down through the collector and into the switching region. A "drip cone" above the tube opening allows Cs vapor to condense and flow to the side-walls of the reservoir where it can drop into the pool of liquid Cs at the base of the reservoir. The emitter heater consists of a tungsten spiral element located within the machined molybdenum emitter electrode. The grid is a honeycomb construction of tantalum ribbon, approximately 1 mm thick, with 1 mm diameter apertures. The insulators between emitter, grid, and collector are made of Y_2O_3.

SP1 is approximately 45 cm in length and 8 cm at its maximum diameter. The large length of the prototype is strongly influenced by the necessity to provide a low thermal conductivity between the high-temperature envelope (~500° C) near the switching region and the relatively cool Cs reservoir (~145° C).

Barium is used primarily to provide enhanced cathode emission, and cesium is used primarily as the ionizing medium. In the fabrication of SP1, barium was placed into an annular container near the emitter in the form of barium-oxide and aluminum particles prior to evacuation of the prototype. After the prototype was evacuated and outgassed, the emitter heater was used to heat the barium-oxide and aluminum mixture to approximately 1100° C in order to initiate the reaction

$$3BaO + 2Al \rightarrow Al_2O_3 + 3Ba \ .$$

The "pure" Ba released by this reaction then flowed down to an annular reservoir located approximately 5 cm below the working surface of the emitter. This reservoir is located so that the Ba will be at a temperature of approximately 550° C when the emitter is at a temperature of 1100° C. After the Ba reaction was completed, the device was heated in such a manner that the Cs reservoir was the coolest point in the device, then Cs vapor was introduced into the prototype to condense in the Cs reservoir. When the Cs loading process was completed, the device was permanently sealed.

Description of Sealed Prototype Test Stand

The test stand consists of a vacuum chamber with a base pressure of 10^{-7} Torr and feedthroughs for emitter heater leads, Cs reservoir heater leads, thermocouples, bias power leads for the emitter and collector, and control leads for the grid. The I-V power supply consists of a half-wave rectified transformer fed by a variac. This supply provides a variable amplitude signal that sweeps from zero voltage up to a maximum value and then back to zero. An Electronics Measurement Inc. TCR 120T40 power supply, providing a dc collector bias of up to 120 V at 40 A, is used for modulation tests. The data acquisition and control system consists of an 80486 PC running a software application written in the National Instruments LabWindows development environment. The acquisition and control application is interfaced to a LeCroy 9304 (4-channel) 175 MHz digital oscilloscope for current and voltage measurements and an ADAC Corp. 5302EN I/O module for thermocouple measurements and I/O control signals. Current measurements are accomplished through the use of current shunts.

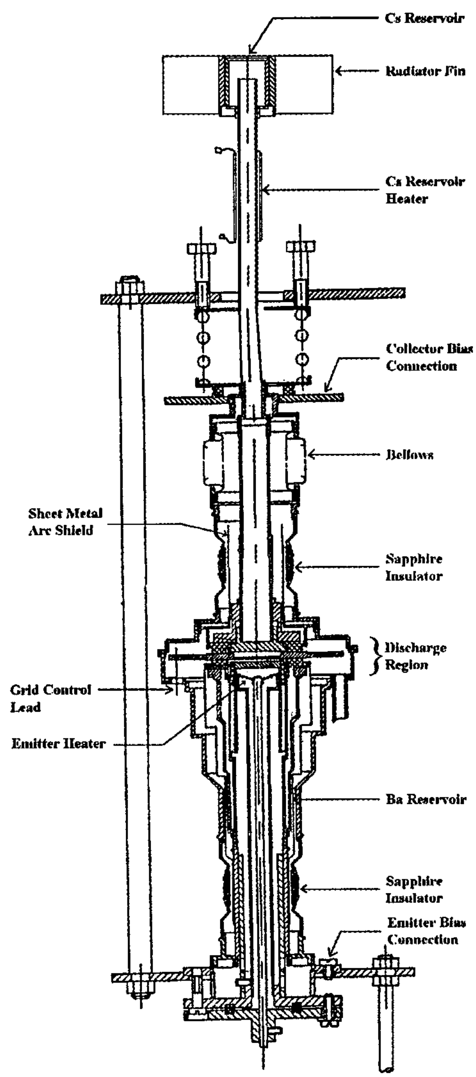

Fig. 1. Schematic illustration of the first sealed prototype Cs-Ba tacitron.

Due to the sealed nature of the device, emitter and Ba reservoir temperatures could not be measured. Only Cs reservoir temperatures were measured directly. Since emitter and Ba reservoir temperatures can only be inferred from temperature profiles provided by Kurchatov, direct performance comparisons between the sealed prototype and previously studied demountable devices are only approximate.

Experimental Results

Fig. 2 shows an I-V characteristic taken from the sealed prototype device. The "knee" of the I-V curve occurs at 5.7 A and 2.1 V. The emitter heater current for this measurement was 26 A, corresponding to approximate emitter and Ba reservoir temperatures (from Kurchatov's thermal mapping curves) of 1100° C and 620° C, respectively. The measured Cs reservoir temperature, T_{Cs}, was 107° C, corresponding to a Cs vapor pressure on the order of 10^{-3} Torr. Note that ignition occurred at a collector bias, V_{cc}, of 4.8 V, and the forward voltage drop, V_f, is approximately 2 V. By way of comparison, the Cs reservoir temperatures at which demountable Cs-Ba tacitrons, with similar gap spacing and grid design to the sealed prototype, have been reported[9,14,17] to achieve ignition at less than 10 V are greater than 130° C. Forward voltage drops of 2 V are also reported[9,14,17] only at T_{Cs} greater than 130° C. This implies a discharge region Cs pressure, for the measurement shown in Fig. 2, that is significantly higher than that given by the Cs reservoir temperature.

This discrepancy is attributed to Cs migration from the reservoir to other parts of the switch (e.g., the alumina byproduct of the Ba loading process) during shipment. This migration is made possible by the fact that Cs melts at only 29° C, and SP1 was not shipped in a fixed upright orientation to prevent liquid Cs from flowing down into the lower part of the switch. Maintained at operating temperature for a sufficient period of time, any stray Cs should return to the Cs reservoir. However, the grid-collector gap shorted early in the test schedule, evidently before all the Cs could return to the reservoir. Hence, T_{Cs} is not a reliable indicator of Cs vapor pressure for these tests of the sealed prototype.

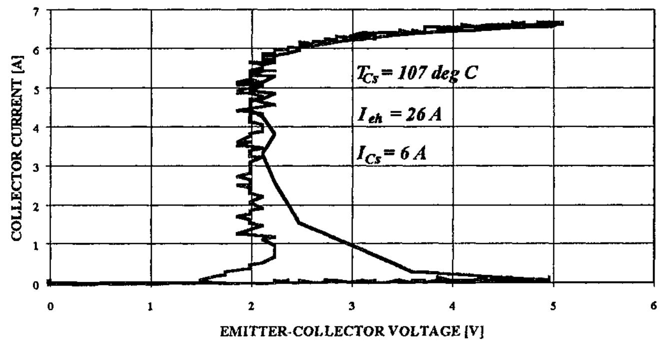

Fig. 2. Sealed Prototype Characteristic I-V Curve

The "knee" of the I-V curve in Fig. 2 corresponds to an emission current density of approximately 3 A/cm^2. It is expected that emission current densities greater than 10 A/cm^2 can be achieved with machined molybdenum electrodes in Ba vapor, however, at a sustained emitter heater current greater than approximately 25 A, the collector-emitter gap of SP1 consistently short-circuits. Electrical measurements made during device cool-down exhibit a rapid step-wise increase in resistance as the prototype cools and the short opens, consistent with a mechanical short induced by thermal expansion of some internal conducting structure. Hence, increased emission could not be reliably achieved by increasing the emitter temperature of the sealed prototype. It is also possible that the relatively low emission current is due to a poorly optimized Ba pressure or poor quality Ba that is contaminated by undesireable byproducts from the Ba formation reaction (e.g., excess oxygen or aluminum).

Table I below shows some typical operating data for the sealed prototype. As expected, with increasing emitter heater current, I_{eh}, the forward voltage drop, V_f decreases. In addition, the I-V knee current, I_k, increases with increasing cesium vapor pressure (corresponding to T_{Cs}). Note that the I-V parameters in Table I, corresponding to I_{eh} = 29 A, were taken early in the testing series, before V_f began responding to changes in T_{Cs} and before the collector-emitter gap began exhibiting the thermal short-circuit behavior noted above.

Modulation tests of SP1 are inconclusive. The grid-collector gap shorted prior to attaining successful modulation. The most that can be reported from the few tests conducted prior to failure of the grid-collector gap is that the device ignited, and responded to grid input. Positive grid pulses applied during conduction resulted in grid currents (~1 A) much lower than expected, implying that the grid may have been damaged in such a manner that the grid surface area exposed to the plasma is much less than intended. This matter will remain unresolved until such time as a post-mortem is performed on the prototype.

Table I. Sealed Prototype Typical Operating Characterisitics

I_{eh}[A]	T_{Cs} [°C]	V_i [V]	V_f [V]	I_k [A]	V_k [V]
24.0	93.8	6.7	3.1	1.4	3.8
25.3	103.3	> 10.0	2.9	3.0	3.5
26.0	94.3	6.5	2.4	2.3	2.9
26.0	107.0	4.8	2.1	3.0	2.5
29.0	71.8	3.2	1.1	> 8.0	> 1.8

Conclusions

This first sealed Cs-Ba prototype has successfully demonstrated Cs and Ba containment within a sealed metallic envelope, circumventing the problem of developing reliable metal-to-ceramic seals that can survive in a reactive metal vapor. The I-V tests demonstrate a forward voltage drop of approximately 2 V at a current density of roughly 3 A/cm^2. It should be possible to attain I-V current densities of at least 10 A/cm^2. Emission in this first prototype is limited by an emitter-collector short apparently induced by internal thermal expansion at sustained emitter heater currents greater than 25-26 A. The nature of this short suggests that it may be due to thermal expansion of one of the sheet metal arc shields. It is also possible that emission is limited by contamination of the Ba by undesireable byproducts from the Ba loading reaction.

Modulation results are incomplete due to the failure of the grid-collector gap insulator before the desireable operating regime was found. The precise nature of the grid-collector gap failure is not yet known, however, it appears to be independent of temperature, which implies that it is probably a mechanical failure rather than a coating of stray Ba or Al from the Ba loading process. The present theory is that a spot weld failed on one of the tantalum ribbons in the grid structure, allowing the ribbon to physically contact the collector. Prior to failure, the sealed prototype demonstrated definite conduction response to grid input.

An advantage of loading Ba via the $3BaO + 2Al$ reaction is that pure Ba need not be handled during the process. A disadvantage is that Ba vapor pressure may reach 10 Torr during this process[15], allowing the possibility that Ba may condense on the insulator surfaces in the switching region, shorting the electrodes together. The formation of a porous Al_2O_3 during the Ba loading reaction may also contribute to a loss of Cs reservoir control over Cs pressure within the device. In an attempt to alleviate these problems, Kurchatov has modified the Ba loading procedure[16] -- the collector assembly has been modified so that pure Ba can be dropped into the reservoir location immediately prior to device evacuation. The Ba can then be heated and outgassed to remove oxidation prior to the introduction of Cs into the device.

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